the GENERAL RADIO Experimenter

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Since 1915 — Manufacturers of Electronic Apparatus for Science and Industry

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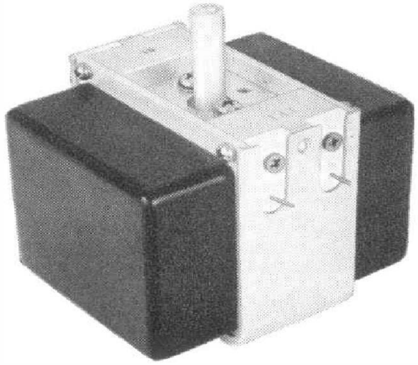
NEW DECADE CAPACITORS WITH POLYSTYRENE DIELECTRIC

Also IN THIS ISSUE

Mica, a natural material, has long been the outstanding dielectric for capacitors and, for many applications, has not been superseded. It is still used almost universally, for instance, for a-c standard capacitors and will undoubtedly continue to be used in this application for a long time. In many respects, however, some of the newer synthetic materials exhibit characteristics superior to those of mica.

Among the materials available in a form economically suited for capacitor manufacture is polystyrene. This material possesses very nearly the ideal characteristics: dielectric constant and low dissipation factor that are invariant with frequency. Measurements from dc to at least several hundred megacycles show substantially constant values of these parameters. Mica, on the other hand, exhibits marked polarizations at frequencies below the audio range. These are manifested by rising values of capacitance and dissipation factor at the low end of the audio range. The relaxation times of these polarizations

Figure 1. View of the Type 980-A Decade Capacitor Unit.



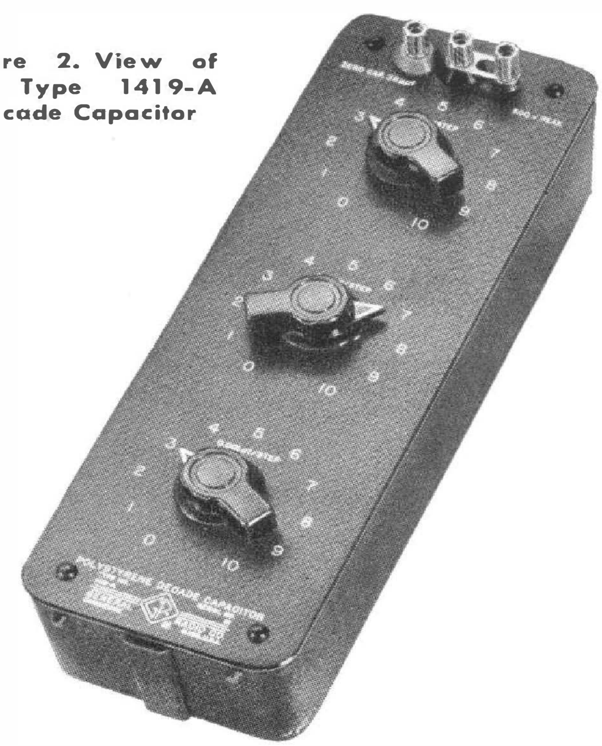


Figure 2. View of the Type 1419-A Decade Capacitor

correspond to frequencies in the tenths and hundredths of cycles per second and appear even in the millicycle and microcycle range. These polarizations are believed to be interfacial, resulting presumably from the laminar structure of the mica.

A thorough discussion of polarization in dielectrics is beyond the scope of this article. These phenomena can be described either in the frequency domain in terms of dielectric constant and loss factor (complex dielectric constant) or in the time domain in terms of the time variation of current resulting from changes in applied d-c voltage. The d-c response is often expressed in terms of "apparent resistance," and in fact most short term insulation-resistance measurements are actually nothing more than a measure of the charging current flowing into the low-frequency polarizations.

Terminology is as yet not well standardized. Terms such as "dielectric absorption," "soakage," "voltage recovery," and "d-c capacitance" have been used. The difficulty is that such terms can be relatively meaningless unless the method of measurement is specified. It is to be hoped that standardization on terminology, specifications, and method of measurement will soon be reached [1] in these areas, which appear to be of growing interest.

Capacitors carefully made of properly processed polystyrene can be shown to be about two orders of magnitude better than an equivalently carefully made mica capacitor. For example, Mr. R. F. Field reports [2] observations of high-quality, silvered-mica capacitors that show rises in capacitance as great as 30%, while similar measurements on the polystyrene units described later indicate rises of only a few tenths per cent. These measurements of discharge current vs. time were taken over a period of weeks and thus correspond, in the frequency domain, to measurements in the microcycle range.

Early Applications

The potentialities of polystyrene as a capacitor dielectric were recognized in the late thirties, and since about 1940 General Radio has carried on a program of development, and manufacture for its own uses, of polystyrene capacitors. Our first commercial application was in tuning networks in the TYPE 762 Vibration Analyzer, in the frequency range down to 2.5 cycles. In this application other available capacitors were unsatisfactory. Mica was not only out of the question because of cost, size, and weight in the large capacitance values required, but the polarization mentioned above caused anomalous behavior at the low frequencies. Subsequent uses of such capacitors include the TYPE 1611-A Capacitance Test Bridge. In this instrument, a 1-μf polystyrene capacitor accurate to 0.25% is used as a standard. Field use in many hundreds of these bridges over a period of ten years has shown these capacitors to be entirely satisfactory from the points of view of stability and life expectancy. Capacitors of this type have thus demonstrated their performance and reliability and are now offered for sale in the form of decade units.

These polystyrene-dielectric capacitors, owing to their very low dielectric absorption, are particularly useful in research and development work on computor and integrator circuits, and on low-level a-c amplifiers. Because of their constancy of capacitance and dissipation factor with frequency, they

[1] Sections A and C, Subcommittee XII, ASTM Committee D-9 are interested in this work. The writer will welcome any comments or the participation of anyone interested.

[2] Unpublished data.

make excellent components for measuring circuits, filters, and tuned circuits. They are nearly ideal capacitors for d-c work, because of their high insulation resistance and low dielectric absorption.

TYPE 980 DECADE CAPACITORS

Decades for assembly into other equipment are available in three capacitance ranges, with capacitance at maximum setting of 1.0, 0.1, and 0.01μf.

Each decade consists of four capacitors of magnitudes in the ratios 1–2–2–5. The switch selects parallel combinations to give increments over zero capacitance in all integral values from 1 to 10.

The individual capacitor units are non-inductively wound and carefully heat treated. The tape used is cast of purified high-molecular-weight polystyrene, pre-stretched only in the direction of winding. During heat treatment the units are carried beyond the transition temperature of the polystyrene, and the shrinkage of the tape produces an extremely firm, stable unit, which is insensitive to pressure, and which is stable in retrace capacitance value for temperatures up to 65° C.

The units are hermetically sealed in black-finished brass cans, having Teflon feed-through insulators to assure high resistance even under adverse humidity conditions. No impregnant, which might jeopardize the low-frequency performance, is used.

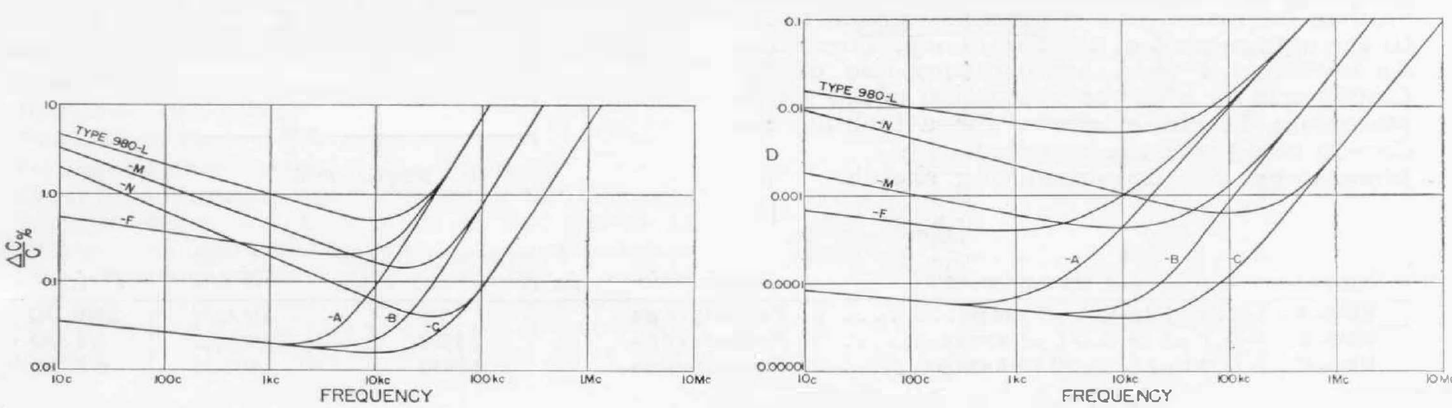
The cased units are mounted to a newly developed cam-type decade switch. The supporting dielectric material of the switch, including the shaft, is heat-resistant cross-linked polystyrene, and Teflon spacers support the rigid-wire leads.

Low-Frequency Performance

The resulting decade capacitor assembly has an insulation resistance greater than 10^{12} ohms under standard laboratory conditions (23° C, 50% RH) when measured at 100 volts. Dissipation factor is typically of the order of 0.0001 in the audio frequency range, and is specified not to exceed .0002 at frequencies down to 100 cycles. A slight rise occurs as frequency approaches zero, as shown in the plot of Fig. 3. Theory [3] indicates that the maximum value of dissipation factor (from dielectric loss) cannot be greater than one-half the value of the rise in capacitance. Measurements indicate that this maximum value is of the order of 0.0005.

[3] The "circular-arc" theory proposed by Cole and Cole.

Figure 3. Typical plots of change in capacitance and dissipation factor as a function of frequency for Type 980 Decade Capacitor Units. Types 980-A, -B, and -C are polystyrene units; Types 980-L, -M, -N, and -F are paper and mica units. Capacitors are adjusted to their rated accuracy at 1 kc.



In addition, at some sufficiently low frequency, the leakage resistance becomes significant in determining dissipation factor. At 10^{-4} cycles, the 10^{12} ohms resistance of one microfarad produces a dissipation factor of 0.001.

One of the most convenient means of measuring d-c performance is by the voltage-recovery method. If a capacitor is charged for a given period of time and then short-circuited through a protective resistor for a period long enough to discharge the high-frequency capacitance, the charges in the long-time polarizations remain. These charges gradually transfer to the high-frequency capacitance and appear as a measurable potential at the terminals. If these capacitors are charged for one hour and then discharged for 10 seconds, the ultimate recovered voltage is 0.1% or less of the original charging voltage. In contrast, even a good mica capacitor may recover 10% or more, while some impregnated paper capacitors may show recoveries approaching the charging voltage.

In terms of frequency characteristic the above performance is equivalent to an increase in capacitance of 0.1% at a frequency of the order of 10^{-4} cycles.

High-Frequency Performance

At frequencies above a few hundred cycles, the dissipation factor of the material seems to reach a "floor" and remains constant, as does the dielectric constant. The terminal values of capacitance and dissipation factor, however, are modified by the residual inductance and series resistance of the capacitors, switch structure, and leads. The capacitance change increases as the square of the frequency, while the dissipation factor change varies as the 3/2 power of frequency. Representative plots of these variations are shown in Fig 3.

SPECIFICATIONS

Accuracy: Capacitance increments are within ± 1% from zero position when measured at 1 kc. The units are checked with the switch mechanism high, electrically, and the common lead and case grounded. The zero capacitance is 10 μμf and must be added to the switch settings to give the total capacitance.

Dissipation Factor: Less than 0.0002 at 1 kc and 23°C, 50% RH

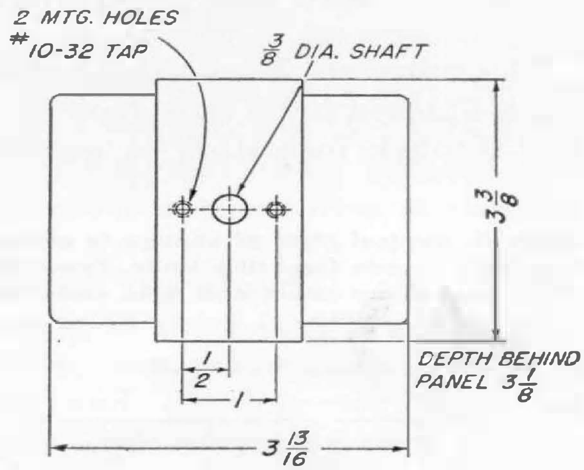
Frequency Characteristics: Figure 3.

Maximum Voltage: 500 volts d-c or peak at frequencies below the limiting frequencies tabulated below. At higher frequencies the allowable voltage decreases and is inversely proportional to the square root of the frequency. These limits correspond to a temperature rise of 40° Centigrade for a power dissipation of 3.5 watts.

Mounting: Machine screws for attaching the decade to a panel are supplied.

Dimensions: See accompanying sketch.

Net Weight: 2 pounds, 2 ounces.



980-A,-B,-C

Type	Capacitance	Dielectric	Frequency Limit in Kc-Max. Volt.	Code Word	Price
980-A	1.0 μf in 0.1 μf steps	Polystyrene	10	AVAST	$66.00
980-B	0.1 μf in 0.01 μf steps	Polystyrene	100	AVERT	51.00
980-C	0.01 μf in 0.001 μf steps	Polystyrene	1000	AVOID	57.00

TYPE 1419-A DECADE CAPACITOR

A three-dial decade capacitor having a range from .001 μf to 1.11 μf in steps of .001 μf is also available. The individual TYPE 980 decades are mounted on an aluminum panel, in an aluminum cabinet, providing complete electrostatic shielding. A separate ground post is provided, so that the capacitor may be used in either two-terminal or three-terminal applications, with case grounded.

SPECIFICATIONS

Capacitance Range: .001μf to 1.11μf in steps of .001μf. The three decades have steps of .001, .01, and .1μf respectively.
Zero Capacitance: Approximately 35$\mu\mu$f.
Accuracy: Individual capacitors are adjusted to an accuracy of $\pm$ 1%. The capacitance at the terminals, less the zero capacitance, is within $\pm$ 1% of indicated value for any setting
Dissipation Factor: Dissipation factor caused by dielectric loss is less than 0.0002 at all frequencies above 100 cycles. At high frequencies, series metallic resistance increases the dissipation factor as shown by the curves of Figure 3.
Insulation Resistance: Greater than 1 megamegohm (10^{12} ohms), when measured at 100 volts, 23° C, and 50% RH.
Maximum Voltage: 500 volts d-c or peak.
Frequency Characteristics: The d-c capacitance is equal to the 1-kc value within 0.1%. At high frequencies, series inductance causes capacitance to increase as shown by the curves of Figure 3.
Dielectric Absorption: See Voltage Recovery.
Voltage Recovery: The voltage recovery at the terminals is less than 0.1% of the original charging voltage, after a charging period of one hour and a 10-second discharge through a resistance equal to one ohm per volt of charging.
Mounting: Aluminum panel and cabinet.
Dimensions: (Length) 13 x (width) 4$\frac{5}{16}$ x (depth) 5 inches, over-all.
Net Weight: 8$\frac{3}{8}$ pounds.

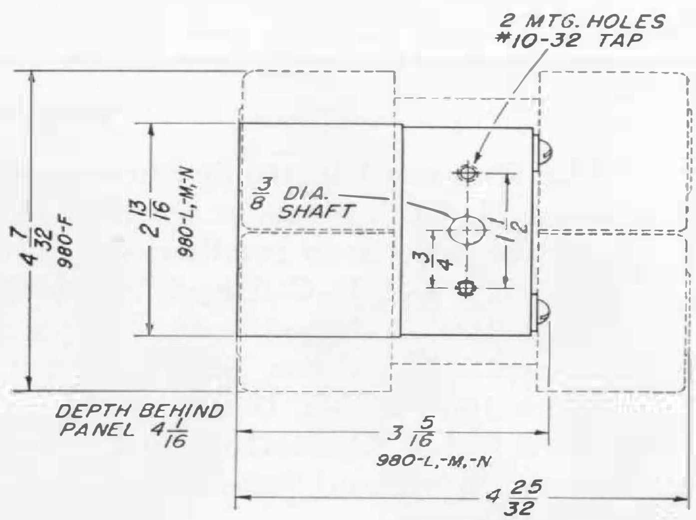
Type		*Code Word*	*Price*
1419-A	**Decade Capacitor**	BIGOT	**$195.00**

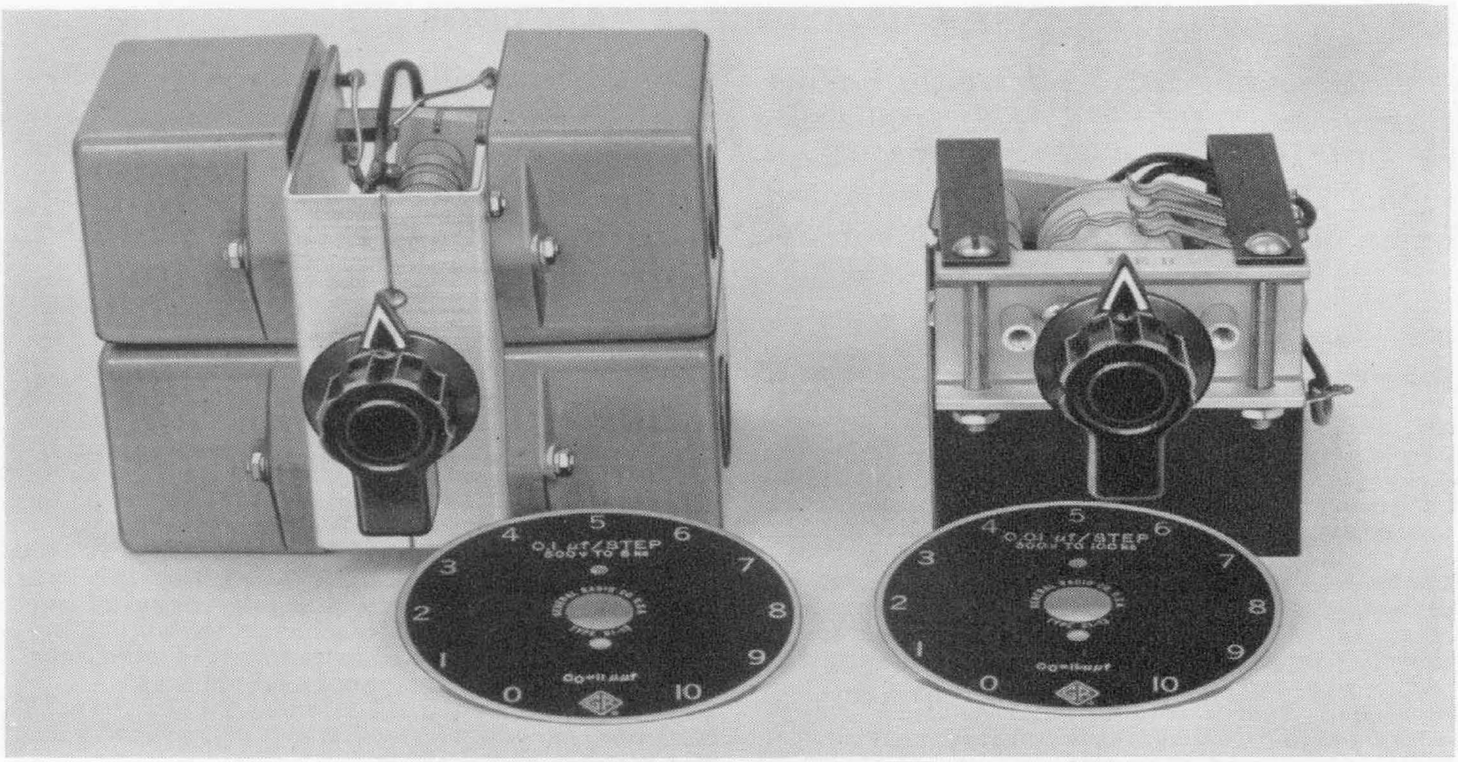
DECADE CAPACITORS WITH MICA AND PAPER DIELECTRICS

The new decade switch is now also used for mica and paper decade capacitors. The new assemblies replace the former TYPE 380, with identical mounting dimensions. A listing of these units is given, with specifications, below. The low-loss switch, plus improvements in the mica capacitors themselves, result in lower dissipation factor than that specified for the superseded TYPE 380 Units.

SPECIFICATIONS

Accuracy: Capacitance increments on all units are within $\pm$ 1% from zero position when measured at 1 kc except the TYPE 980-L, which is accurate within $\pm$2%. The units are checked with the switch mechanism high, electrically, and the common lead and case grounded. The zero capacitance of all units is 10$\mu\mu$f and must be added to the switch settings to give the total capacitance.
Dielectric: See table.
Dissipation Factor: See table.
Frequency Characteristics: See Figure 3.
Maximum Voltage: 500 volts peak for all units (except 980-L which is rated at 300 volts) at frequencies below the limiting frequencies tabulated below. At higher frequencies the allowable voltage decreases and is inversely proportional to the square root of the frequency. These limits correspond to a temperature rise of 40° Centi-





View of the Type 980-F (left) and Type 980-N (right) Decade Capacitor Units.

grade for a power dissipation of 2.5 watts for the TYPE 980-F and 3.5 watts for all other units.
Mounting: Machine screws for attaching the decade to a panel are supplied.

Dimensions: See accompanying sketch.
Net Weight: TYPE 980-F, 3 pounds, 12 ounces; TYPE 980-L, 1 pound, 10 ounces; TYPES 980-M and -N, 1 pound, 8 ounces.

Type	*Capacitance*	*Dielectric*	*Dissipation Factor at 1 kc and 23° C*	*Frequency Limit in Kc for Max. Voltage*	*Code Word*	*Price*
980-F	1.0 μf in 0.1 μf steps	Mica	Less than 0.0003	5	ACUTE	$128.00
980-L	1.0 μf in 0.1 μf steps	Paper	Less than 0.010	1	ADAGE	28.00
980-M	0.1 μf in 0.01 μf steps	Mica	Less than 0.001	100	ADDER	42.00
980-N	0.01 μf in 0.001 μf steps	Mica	Less than 0.001	1000	ADDLE	26.00
980-PI	Switch only				SWITCHBIRD	11.00

WESCON 1956

The Western Electronic Show and Convention will be held in Los Angeles, August 21–24. Visit us in booths 918 and 919 to see the new GR instruments that you have been reading about in the *Experimenter*, including:

TYPE 1230-A D-C Amplifier and Electrometer
TYPE 1605-A Impedance Comparator
TYPE 1391-A Pulse, Sweep, and Time-Delay Generator
TYPE 1603-A Z-Y Bridge
TYPE 874-LBA Slotted Line, with TYPE 874-MD Motor Drive
TYPE 907-R and 908-R X-Y Dial Drives

TYPE 1420 VARIABLE AIR CAPACITOR

A NEW, HIGH-QUALITY COMPONENT FOR INSTRUMENT USE

The concept of machining a parallel-plate type of variable air capacitor from solid metal, although not a new one, is unique among contemporary manufacturers. The main features of the new Type 1420 Capacitors (Fig. 1) are derived from this technique, which offers advantages, both mechanical and electrical, over more conventional methods.

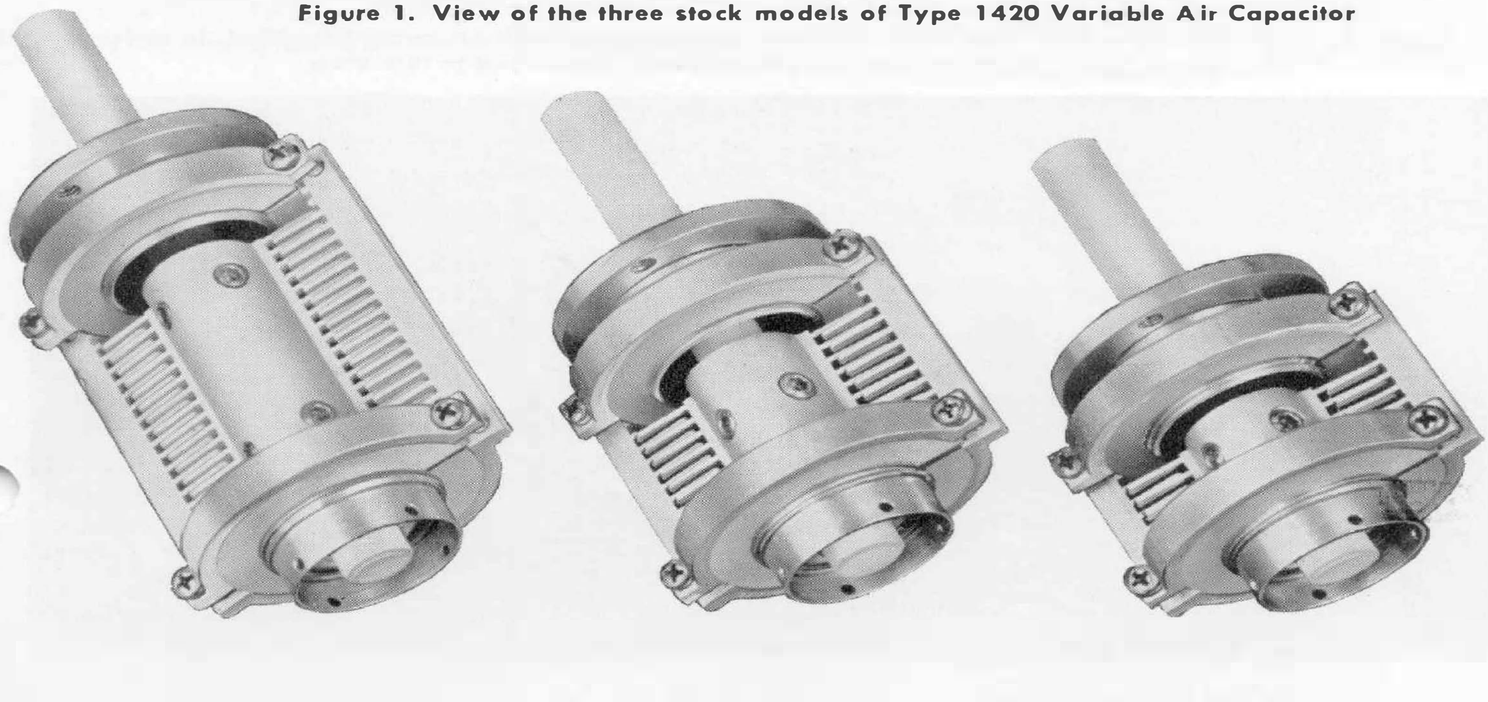
Certain mechanical advantages are obvious. Machining is inherently a more precise operation than rolling, so that plates can be better controlled in thickness and straightness. Gang milling eliminates the cumulative spacing errors imposed by piece tolerances on a stacked structure, and turning and boring on a single piece insures better concentricity than can be obtained in a composite assembly. The integral-plate construction makes a sturdy structure with high mechanical stability.

Electrical performance gains are equally apparent. The precise machining produces inherently good linearity and control of capacitance magnitude. The homogeneous nature of the conductors yields lower metallic resistance and inductance than even a soldered stack and provides low thermal drift. The ruggedness of the plates minimizes microphonic tendencies.

The General Radio Company, in the light of the advanced state of the arts of aluminum extrusion alloys and cutting tools, undertook the development of a practical capacitor incorporating the foregoing advantages. Although the improved performance for this construction in an instrument-grade capacitor would warrant a cost premium, it was discovered that the proper combination of free-machining aluminum alloy with tungsten-carbide tools in a special machine (Fig. 3) produced superior one-piece plate assemblies at less cost than the conventional punching, stacking and soldering methods.

The design of the Type 1420 Variable Air Capacitor, delineated in Fig. 2, takes further advantage of the machining process to provide a number of extra features. Because the stator (1) is plunge cut, the resulting plates are completely joined on their outer pe-

Figure 1. View of the three stock models of Type 1420 Variable Air Capacitor



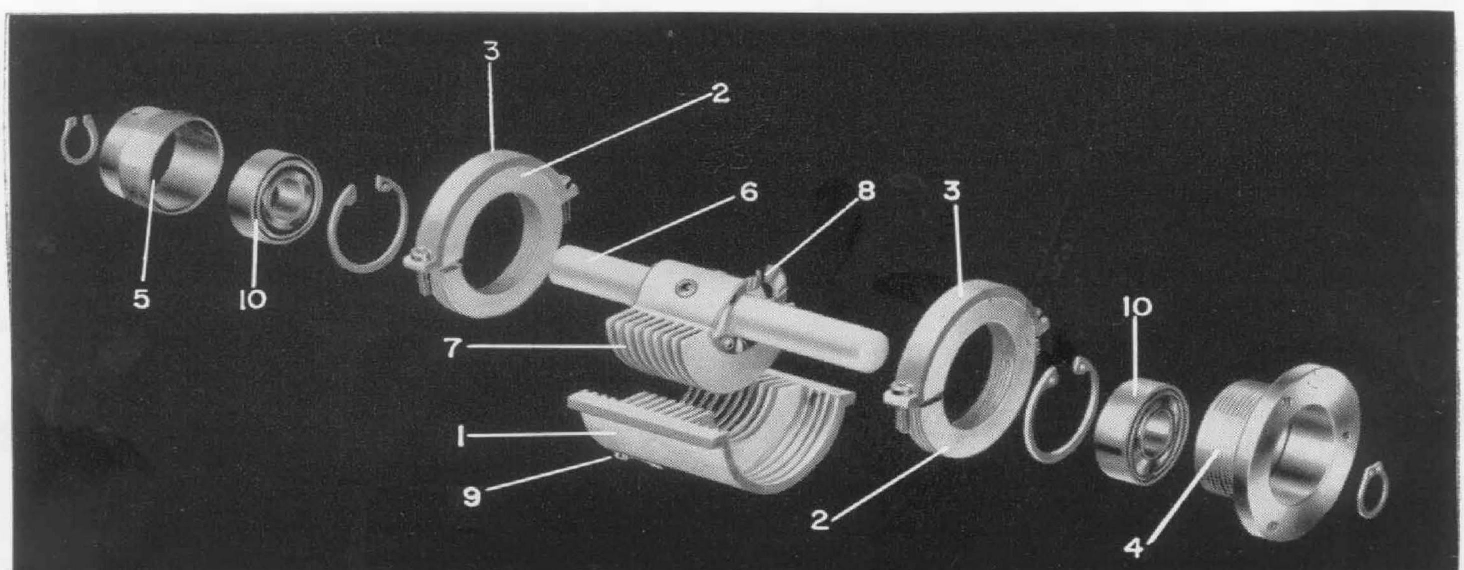
ripheries. This eliminates irregularities in the capacitance-vs.-rotation curve which might otherwise be caused when the rotor passes the vicinity of a stator supporting post or strut, helps to minimize resistance and inductance, and makes the part rigid enough to serve as the supporting frame for the whole capacitor. Use of the stator as a frame is accomplished by concentrically boring out all but 1/32 in. of the four plates on each end of the piece. Precisely fitted polystyrene insulators (2) are matched to these bored ends and held by clamps (3). The vestigial plates in both stator and clamps lock the insulators axially.

Polystyrene is an ideal dielectric material for the insulators of an air capacitor, because of its low dielectric constant and extremely low losses. Although it is thermally and mechanically unsuitable in most structures, the insulators in the TYPE 1420 are machined from a cast bar of cross-linked polystyrene for thermal adequacy and are stressed entirely in compression over a wide area to eliminate crazing or other structural failure.

These insulators have tapped center holes and are slit, to mate with and to clamp on to, threaded bearing cages (4) and (5), thereby permitting micrometer adjustment and subsequent locking of the ball bearings (10), which support the shaft (6). The shaft is of glass-reinforced polyester, filled with long axial fibers, similar to a modern fishing rod, and is of exceptional strength and stability as well as being good electrically. The use of an insulating shaft isolates the rotor for three-terminal connections and takes the ball bearings out of any electrical path. It is well known that the erratic conductivity of ball bearings produces electrical noise even when well shunted by parallel sliding contacts.

The rotor (7) is simply and firmly attached to the shaft by setscrews transverse to a closely fitted through hole. The concentricity of the rotor is insured, because the plates are milled and turned on a centered arbor held by the setscrews exactly as the shaft is secured in assembly. The front end bearing cage (4) has a flange by which the capacitor is mounted, and the rear cage (5) has a thin-walled, perforated extension to which a rotor connection may be soldered. Electrical connection to the stator is normally made by a solder lug (9) which is affixed adjacent to the rotor terminal to aid in providing short leads to associated circuitry.

Figure 2. Exploded view of a Type 1420 Variable Air Capacitor with elements identified. In order to show the split-spring ring contact, the rotor is reversed in this view.



A coin-silver, split-spring ring (8) is attached permanently to the rotor with drive pins and has two independent sliding contacts brushing the rear bearing cage. In the General Radio Type 1606-A R-F Bridge, a special reversed version is used, in which the rotor brush makes contact with the front bearing housing to provide a grounded rotor.

The rotor, stator, and clamp blanks are cut off from shaped extruded rods (Fig. 4). The aluminum alloy is identical in these parts to eliminate differential expansions and consequent thermal capacitance drift. The bearing cages are of brass, bright-alloy plated, and the full size (standard inch series $\frac{3}{8}''$) ball bearings are double shielded, packed with wide-temperature-range lubricant and are suitable for continuous motor drive. In the Type 1606-A R-F Bridge these capacitors have passed all the environmental tests of MIL-T-945-A.

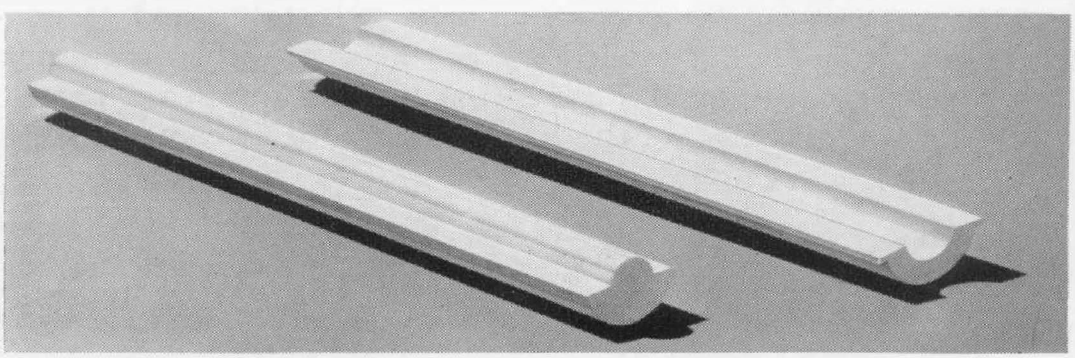
An interesting application of the Type 1420 Capacitor is shown in Fig. 5. This small, plug-in, general-purpose variable capacitor is shielded and equipped with a coaxial connector. The design takes advantage of the good high-frequency characteristics of the Type 1420, as well as its compactness, ruggedness and reliability.

Figure 3. Designed and built in General Radio's tool department, this machine automatically mills the rotors and stators from the aluminum extrusions shown in Figure 4.

The General Radio Company has had several years experience in the manufacture and use of these milled plate capacitors in proprietary instruments. They are now being offered for sale as a catalog component in the belief that many customers will have applications ideally suited to their many features.

— H. M. Wilson

(Below) Figure 4. Extruded aluminum stock from which rotor and stator are milled. (right) Figure 5. View of the Type 874-VC Variable Capacitor, a shielded unit of the 1420-type, used as a tuning element in coaxial circuits.



SPECIFICATIONS

Capacitance Range:

	Nominal Max.	Nominal Min.	Range for Linear variation
H	250	16	216 ± 5μμf
G	130	14	108 ± 5μμf
F	70	13	54 ± 5μμf

The rotor-to-ground capacitance is about 2μμf, and the stator-to-ground capacitance is about 6μμf, for all sizes. The data in the above table are for the capacitor used as a two-terminal device, with rotor grounded. If stator is grounded, maximum and minimum capacitance values will be decreased by about 4μμf.

Linearity: The variation of capacitance with angle of rotation is guaranteed linear within ± 0.2% of full scale. The angular range of linear variations is 160°.

Typical linearity is better than ± 0.1%.

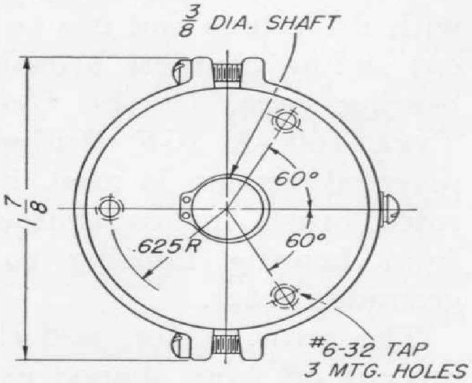
Dielectric Losses: For the grounded-rotor connection, the dielectric losses correspond to a D_oC_o product of less than .01 x 10^{-12}. The rotor-to-ground capacitance has a D_oC_o product of 0.1 x 10^{-12}. This loss component is in parallel with the main capacitance only for the ground-stator connection.

Insulation Resistance: Greater than 10^{11} ohms under standard ASTM laboratory conditions (23° C, 50% RH).

Depth behind panel

F 1¾
G 2⅛
H 2⅞

Shaft Dia. ⅜



Temperature Coefficient of Capacitance: Approximately + .003% per degree C.

Shock and Vibration: Will pass shock and vibration tests of MIL-T-945-A.

Maximum Voltage: 70 volts peak.

Inductance: Approximately 0.006 micro-henry.

Torque: 2 ounce-inches maximum.

Net Weight: TYPE 1420-F, 4 oz; -G, 4½ oz; -H, 5½ oz.

Dimensions: See sketch.

Type		*Code Word*	*Price*
1420-F	**70 μμf, max.**	MARRY	**$20.00**
1420-G	**130 μμf, max.**	MATIN	**21.50**
1420-H	**250 μμf, max.**	MAXIM	**22.50**

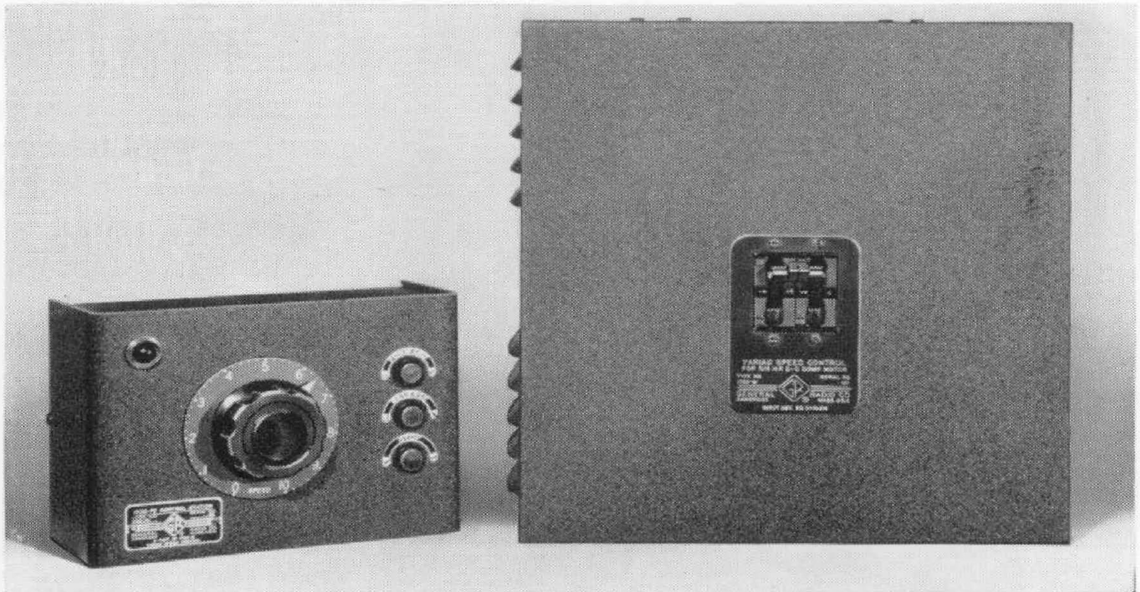
CLOSE-OUT SALE OF TYPE 1702-M MOTOR CONTROL

¾-hp, push-button-controlled model

We have on hand a number of our ¾-hp, TYPE 1702-M Variac® Speed Controls, complete with push-button control stations. This model, which originally sold for $350.00, has been discontinued as a result of the introduction of the new TYPE 1702-BW, which can be used with a drum-type controller to accomplish the same purpose at a lower price.

These controls are brand new and carry our standard new-equipment guarantee. To close out our stock, they are now offered at $175.00 each, just one-half the original price. Circuit and characteristics are identical with those currently supplied on newer models, and the unit is an exceptional bargain at this price, which is well below that of current models.

This control will operate a 115-volt, d-c, shunt or compound motor from a 115-volt, 60-cycle, a-c line. Motor speed is continuously adjustable and is controlled by a Variac® autotransformer. A description will be found on page 3 of the *Experimenter* for December, 1953.



View of the Type 1702-M Variac Motor Speed Control. The small control unit shown at the left can be mounted in any location convenient to the operator.

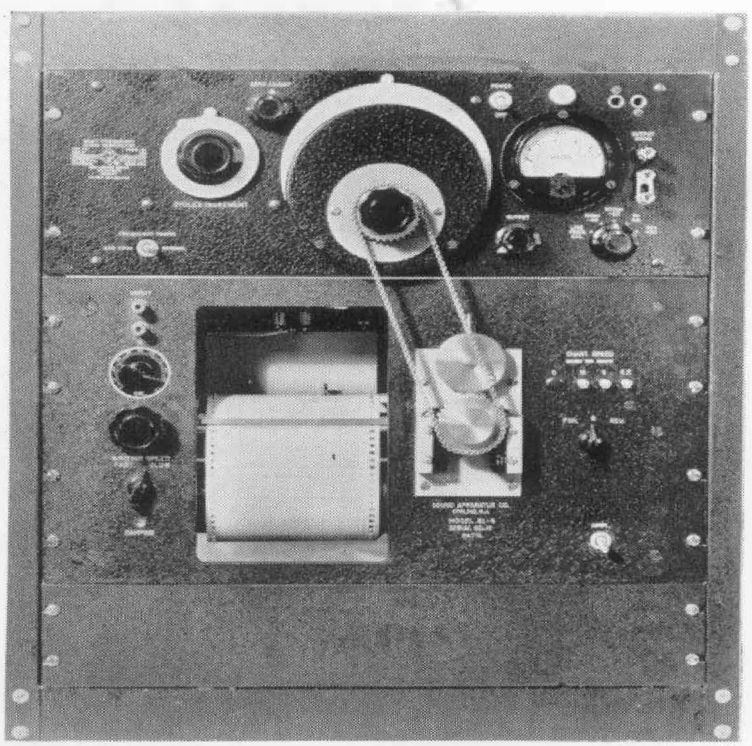
SPECIFICATIONS

Horsepower: ½ and ¾.
Input: 105 to 125 volts, 60 cycles, or 105 to 120 volts, 50 cycles, 10 amperes.
Input Power: 1150 watts, full load; 65 watts, standby.
Electrical Output: Armature supply, 0 to 115 volts, 6.5 amperes, dc; field supply, 115 or 75 volts, 0.4 ampere.
Motor Speed Range: 0 to rated or 0 to 1.15 rated.
Dynamic Braking: Automatic in stop position.
Armature Overload Protection: Circuit breaker at 7.5 to 9 amperes.
Control Station: Remote.
Main Cabinet Dimensions: 13½ x 15 x 6½ inches.
Code Word: WISTY
Price: $175.00.

RECORDER COUPLING FOR THE BEAT — FREQUENCY AUDIO GENERATOR

The Sound Apparatus Company, Stirling, New Jersey, has recently completed the development of its Model SL-4 Recorder. It is designed for the plotting of frequency response curves of electro-acoustical apparatus. With it, response curves of loud-speakers, microphones, filters, equalizers, transformers can be automatically plotted in a very short time. A General Radio Type 1304-B Beat-Frequency Audio Generator is especially recommended by the manufacturer as the generator for driving the equipment under test. Its frequency control dial is attached by a low-backlash chain drive to the motor in the recorder which operates the paper drive. Complete information about the recorder can be obtained from its manu-

Figure 1. View of the Sound Apparatus Company's Model SL-4 Recorder coupled to the General Radio Type 1304-B Beat Frequency Audio Generator.



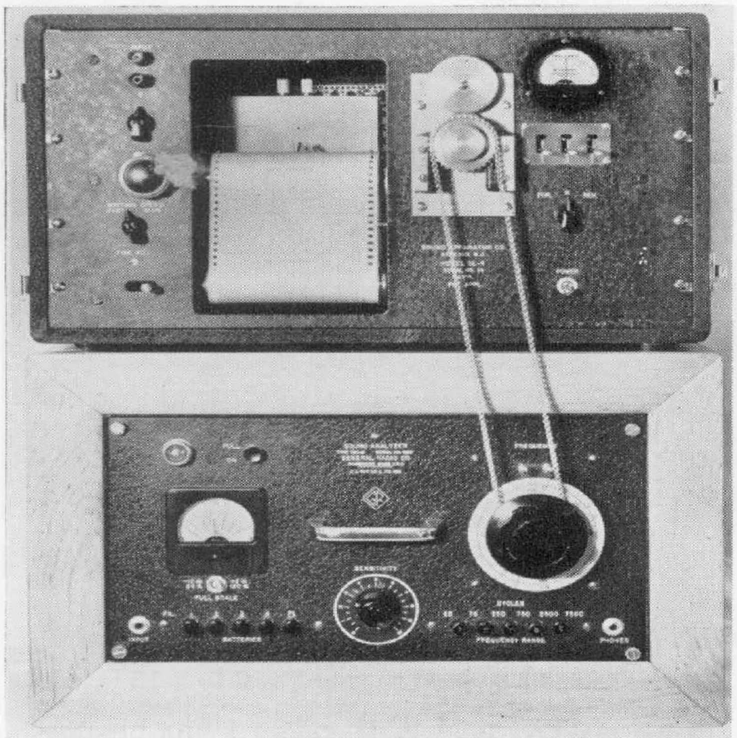


Figure 2. The recorder coupled to the General Radio Type 760-B Sound Analyzer.

facturer. He is equipped to provide the coupling means between the recorder drive and the oscillator.

Here is another application in which the beat-frequency type of oscillator is ideal because the entire audio spectrum may be swept with one rotation of the frequency control dial, eliminating the need for the frequency multiplier adjustments necessary with R-C type oscillators.

Figure 1 shows the Sound Apparatus Model SL-4 Recorder coupled to the Type 1304-B Beat-Frequency and Figure 2 shows the same recorder arranged to drive the Type 760-B Sound Analyzer.

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